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Tree ring density-based warm-season temperature reconstruction since A.D. 1610 in the eastern Tibetan Plateau

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A B S T R A C T

Tree-ring samples from purple cone spruce (*Picea purpurea*) were collected at four sites on the eastern Tibetan Plateau. Maximum latewood density (MXD) was measured by X-ray densitometry and a regional standard chronology was established from the four MXD chronologies using the Regional Curve Standardization (RCS) method. Based on significant correlation between the regional RCS chronology and mean April–September temperature, warm-season (April–September) temperature variability was reconstructed back to 1610 for the eastern Tibetan Plateau. The reconstruction explained 58.5% of the variance in the instrumental period (1961 to 2009). In the past 400 years, there were five cold periods with lower than average and four warm periods with higher than average. The temperature reconstruction captured the unprecedented warming in the 20th century, where the last ten years were the warmest decade in the last 400 years. The Ensemble Empirical Mode Decomposition (EEMD) was used to extract the multi-scale fluctuation of the temperature reconstruction. Four quasi-oscillations with periodicities of 2.2–2.7 years, 5.1–7.9 years, 11.9–15.4 years and 21.8–26.2 years indicated major fluctuations of original temperature. Agreement with other temperature proxies implied a high degree of confidence for our reconstruction and its large-scale spatial representation. The temperature reconstruction showed a warming trend on a longer time scale in the eastern Tibetan Plateau.

1. Introduction

The Tibetan Plateau (TP) is a climate sensitive region (Feng et al., 1998). However, due to a lack of long-term instrumental climate records, the understanding of past climate changes on the TP is dependent on climate proxies, such as tree ring (Shao and Fan, 1999; Liu et al., 2005). During the past two decades, tree-ring widths have been frequently used to infer past climate variations for the eastern TP where virginal forests exist (e.g., Zhang et al., 2003; Bräuning and Mantwill, 2004; Shao et al., 2005; Liu et al., 2006; Gou et al., 2007; Liang et al., 2008, 2009; Yang et al., 2010). However, tree-ring widths integrate climate influences prior to and during the growing season and often record mixed climate signals from temperature and moisture stress, thus yielding less robust temperature reconstructions (Zhu et al., 2011; Liang et al., 2012). In comparison to tree-ring width, maximum latewood density (MXD) is a well-validated summer temperature proxy at northern high latitudes (Briffa et al., 1992; Bräuning and Mantwill, 2004; Fan et al., 2009; Wang et al., 2010), showing a perspective to develop summer temperature-sensitive tree-ring density network in the Tibetan Plateau. However, to date, only a limited temperature number of reconstructions based on MXD are available for the TP (e.g., Bräuning and Mantwill, 2004; Wang et al., 2010; Duan et al., 2010; Sun et al., 2012; Duan and Zhang, 2014; Li et al., 2015).

The objectives of this study are to develop new MXD chronologies; reconstruct past climate changes using these tree-ring chronologies on the eastern TP; assess recent climatic changes in a long-term context. We also tested the hypothesis that temperature-sensitive tree-ring wood density will show warming tendency at least during the past one century.

2. Material and methods

2.1. Study area and climate

The study area is located in the eastern part of the TP, where the climate is mainly influenced by the southwest Asian monsoon (Fig. 1). Observations from the meteorological station in Maerkang (31°54′N, 102°14′E, 2664.4 m.a.s.l) show that the multi-year mean of annual precipitation is about 771.5 mm and the mean annual temperature is 8.7 °C from 1954 to 2009.

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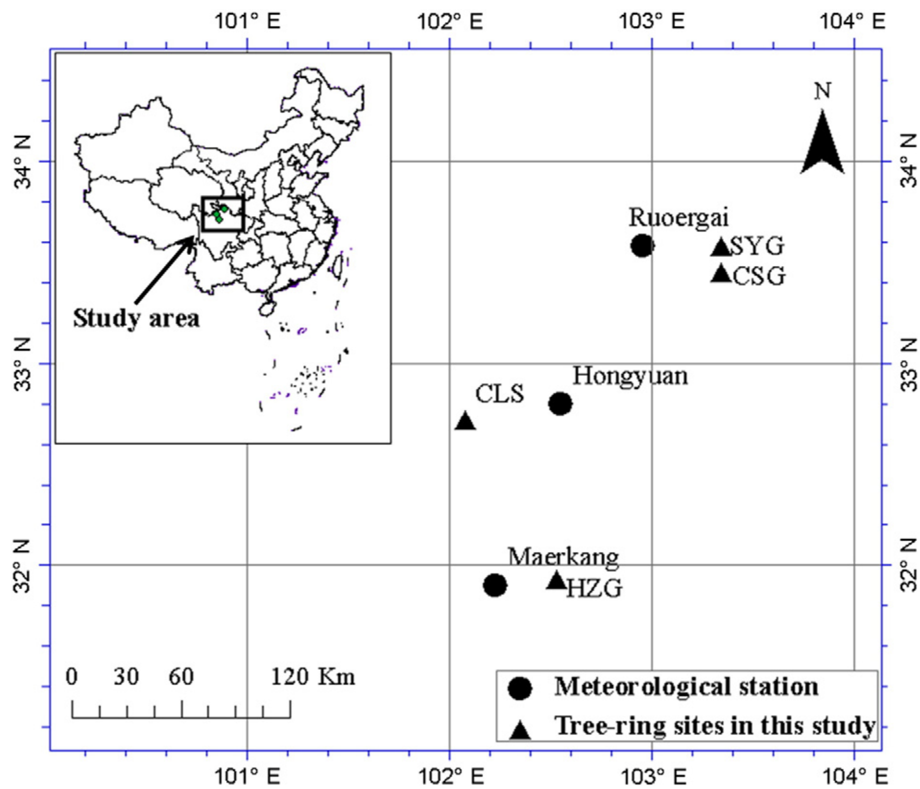

Fig. 1. Locations of the tree-ring sites and meteorological stations.

2.2. Tree-ring sample collection and maximum latewood density chronology development

Purple cone spruce tree-ring samples were collected at four sites in September 2010 in the Qionglai Mountains of the eastern TP (Fig. 1). The forest coverage of the sites ranged from 0.4–0.7, and the slopes ranged from 25 to 30 (Table 1). At least two increment cores were sampled at breast height from each selected tree.

Tree-ring samples were processed following standard dendrochronological practices (Fritts, 1976; Cook and Kairiukstis, 1990). After the increment cores were air-dried, glued to wooden mounts, and sanded in the laboratory, all cores were carefully cross-dated, and the ring width measured with a precision of 0.01 mm. The accuracy of the cross-dating and measurements were then checked using the COFECHA program (Holmes, 1983).

After measurement and cross-dating of ring-widths, the samples were prepared for the densitometric analysis (Lenz et al., 1976; Schweingruber et al., 1988). All densitometric analyses were processed following standard practices at the Laboratory for Climate Studies, China Meteorological Administration. The cores were cut into laths of 1.0 mm thickness with a twin-blade Dendrocut, using angles vertical to the wood fiber. X-ray pictures were taken and the gray-scale variations were measured by the DENDRO2003 instrument, yielding data for seven parameters: earlywood and latewood widths, earlywood and latewood average densities, maximum and minimum densities, and total tree-ring widths. MXD chronology was used in this study. To ensure dating accuracy, the MXD chronology was dated based on tree-ring width cross-dating. The quality of the densitometric cross-dating was also tested using the COFFCHA program.

MXD chronologies for the four sites were developed with the ARSTAN program (Cook, 1985). Regional Curve Standardization (RCS) method was used to remove non-climatic, tree-age related growth trends which still preserved the low-frequency climatic variation in the MXD series (Briffa et al., 1992; Esper et al., 2003). Since significant correlation coefficients from 0.41 to 0.80 ($p < 0.01$) exist among the four sites chronologies over the common period 1850–2000. The MXD chronologies from the four sites were combined into a regional RCS MXD chronology. The expressed population signal (EPS) and running average correlation among series (RBAR) statistics were used to evaluate the signal strength of regional RCS chronology. The regional RCS chronology was considered to be reliable after A.D. 1610 (EPS > 0.85) (Fig. 2).

2.3. Climate data and statistical analysis

Climate data were obtained from the National Meteorological Information Centre, China Meteorological Administration. In order to emphasize the spatial representation, an anomaly dataset averaged from three meteorological stations close to the sampling sites (Maerkang [102°14′E, 31°54′N, 2664.4 m.a.s.l.], Hongyuan [102°33′E, 32°48′N, 3491.6 m.a.s.l], Ruoergai [102°58′E, 33°35′N, 3441.4 m.a.s.l]), including

Table 1
Information about the sampling sites.

Code	Longitude, latitude	Elevation (m.a.s.l.)	Slope	Aspect	TS	Sample (trees/core)
HZG	102°32′, 31°56′	3590	25°	WS	1426–2009	28/70
CLS	102°6′, 32°44′	3817	30°	EN	1558–2009	27/65
SYG	103°21′, 33°36′	2868	35°	S	1574–2009	26/66
CSG	103°21′, 33°28′	3111	25°	E	1655–2009	29/69

TS, time span of purple cone spruce chronology.